CLASSIFICATION CANCELLED

MEMORANDUM REPORT

for

Army Air Corps Materiel Division, War Department

TESTS OF XP-40 AIRPLANE IN N. A. C. A. FULL-SCALE TUNNEL

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INTRODUCTION

At the request of the Army Air Corps Materiel Division, the XP-40 airplane was tested in the N. A. C. A. full-scale wind tunnel to investigate methods for increasing the maximum speed. The major portion of the tests were concerned with measurements of the airplane drag for various modifications of the airplane components such as the cooling systems, landing gear, etc. The investigation also included measurements of the profile drag of the wing and tail by the momentum method, the location of the transition point on the wing, the determination of the critical compressibility velocity for the airplane, and the maximum lift coefficients for the airplane with flaps up and down. A few tests were made with the propeller operating.

The XP-40 airplane is a single-place Curtiss pursuit with the following characteristics:

Gross Weight (production model)--------- 6783 pounds.
Wing Area------------------------------ 236 square feet.
Wing Section--------------------------- 2215-09

Propeller------------------ 3 blades, 11-foot diameter, Curtiss controllable pitch.

Engine--------------------- Allison V-1710-C13.

Normal Rating-------------- 1,000 horsepower at 2,600 r. p. m. at 16,000 feet.

Propeller Shaft Ratio------ 2:1.

METHOD AND APPARATUS

The N. A. C. A. full-scale wind tunnel and the balance equipment used for the force measurements are described in reference 1. The method of mounting the airplane on the balance in the tunnel jet is illustrated in figure 1. The special techniques and apparatus used for the momentum and transition measurements are described in references 2 and 3. The static pressure measurements required for the determination of the critical compressibility velocities were obtained with 1/16-inch diameter static pressure tubes mounted 3/16 inch from the airplane surfaces. The air velocity through the Prestone cooling ducts was measured by means of banks of total head tubes traversing the duct outlets and static pressure orifices in the adjacent duct walls.

TESTS

The test program for the XP-40 airplane was as follows:

1. Power-off force test with the airplane in the completely faired condition (fig. 1). Radiator retracted and completely faired over; exhaust stacks removed; cockpit enclosure closed; landing gear retracted and faired; control surface gaps sealed; propeller removed and spinner holes sealed; bottom of fuselage faired smooth; inlets to oil cooling ducts covered; carburetor inlet scoops and blast tubes removed; control surfaces locked neutral; aerial and aerial fittings off.

2. Same as (1) except lower fuselage fairing removed (fig. 2).

3. Same as (2) except inlets for oil cooling ducts opened (fig. 3).

4. Same as (3) except exhaust stacks added.

5. Same as (4) except the seals on the control surfaces removed (fig. 4).

6. Profile drag measurements by the momentum method were made over the span of the right wing panel and horizontal tail surfaces at the high-speed attitude with the elevator and aileron gaps both sealed and open.

7. Same as (5) except rear wheel cover plates removed from landing gear fairing (fig. 5).

8. Same as (5) except all fairing removed from landing gear (fig. 5).

9. Same as (8) except original carburetor inlet scoops (see upper photograph of fig. 10) added and openings faired over.

10. Same as (9) except blast tubes added with fairing remaining on carburetor scoops.

11. Power-on test with airplane in same condition as in (10) except propeller on and fairing removed from carburetor inlets.

12. Power-on test with airplane in same condition as in (11) except with modified Prestone radiator installation (figs. 6 and 7). Air flow velocity in Prestone radiator duct measured for high-speed and climb conditions.

13. Power-off force tests with airplane same as in (12) except propeller off and fairings added over carburetor inlet scoops. Air flow velocity in radiator duct measured for high-speed and climb conditions.

14. Same as (10) but with original radiator installation (fig. 8) (original airplane minus aerial). Power-off force tests and air flow velocity measurements at high speed and climb conditions.

15. Power-on tests with airplane same as (14) except propeller on and carburetor inlets opened. Air flow measurements at high speed and climb conditions.

16. Same as (14) except original radiator scoop provided with faired inlet and restricted outlet (fig. 9). Power-off tests and air measurements at the high speed condition.

17. Same as (15) except complete landing gear fairing on. Power-on measurements at high-speed condition.

18. Same as (17) except hole at forward end of propeller spinner and openings around blade shanks sealed.

19. Same as (14) with modified carburetor inlet scoop (fig. 10).

20. Same as (1) with aerial added. (Aerial removed after this test and off during all the other tests.)

21. Same as (14), polar taken over maximum lift with flaps up and down.

22. Measurements with surface tubes and static tubes to detect transition at two stations along the wing span.

23. Measurements with static tubes to determine the critical compressibility velocities on the wing, engine cowling, and windshield.

The control surfaces were locked in the neutral position for all the tests. Scale effect on the power-off drag measurements was studied by testing, in most cases, at five tunnel speeds between 63 and 95 m. p. h. For the basic conditions such as (1) and (14) the tests were extended over a range of angles of attack including high speed and climb, whereas in the other conditions the tests were confined to two angles of attack bracketing the high-speed condition. For the power-on tests the propeller pitch was adjusted to provide the correct thrust at the high speed V/nD. This same propeller pitch was maintained for the climb condition and the propeller speed was adjusted to provide the correct resultant thrust. The power-on tests were made at a tunnel speed of about 80 m. p. h.

RESULTS AND DISCUSSIONS

The drag coefficients for the airplane in the high-speed attitudes for the various test conditions are shown in figure 11 and table I. The results are given for a tunnel speed of 90 m. p. h. Typical variations of the drag coefficient with tunnel speed for two of the test conditions are shown in figure 12. The percent drag reduction from various modifications to the airplane is shown in figure 13. These results are to a large extent based on the power-off tests, and the drag coefficients are considered to be accurate to within ±0.0001.

The power-on force test results were erratic owing to the fact that a 1 percent variation in the propeller speed accounted for a drag coefficient change of about 0.0015; however, the averages of numerous test points in general showed agreement with the power-off data. The power-on tests were of particular value for studying the effect of the slipstream on the flow through the radiator ducts.

The lift, drag, and pitching-moment coefficients for the airplane in the original condition are shown in figure 14. Included, also, is a curve of the maximum lift coefficient with the flaps deflected.

Prestone radiator installations. - The greatest emphasis during the test was directed toward reducing the drag of the radiator installation without decreasing the quantity of air flowing through the radiator. The Prestone radiator installation on the airplane as delivered to the N. A. C. A., which is designated as "original" in figure 7, added a C_D increment of 0.0037 to the airplane, which is an increase of 18.9 percent based on the faired airplane C_D of 0.0196. From calculations based on the measured air flow through the radiator and the known radiator resistance it may be shown that of the total drag increment measured for the radiator only 0.0006 or about 16 percent is usefully employed in forcing air through the radiator core. The remaining loss is due to the added frontal area, shape of lip on inlet, and general disturbance of flow over the airplane induced by the scoop arrangement.

In an attempt to reduce the exposed frontal area the radiator arrangement designated as "modified" (fig. 7) was installed on the airplane. For this installation the radiator was raised so as to almost touch the engine crankcase. The scoop was then wholly within the original fairing line of the smooth nose. (See figs. 1 and 6.) With this radiator installation the C_D increment was reduced to 0.0020 or about 10.2 percent of the airplane drag. Compared with the original radiator arrangement a saving in drag of about 8.7 percent is effected. The quantities of air flowing through the two radiator duct arrangements for the high speed and climb conditions, power-off and power-on, are shown in table II. The quantities measured for the two duct arrangements are essentially the same, and both systems should, therefore, provide about equal cooling.

Based on a report from flight tests that the existing radiator installation on the XP-40 provided excessive cooling at the high-speed condition, a single modification was tested in which the outlet area was reduced to 0.6 of the original by means of a flap, and the inlet scoop was refaired so as to have a larger nose radius (fig. 9) in order to provide a smoother passage for the air passing around the duct. The drag increment due to the scoop was reduced to 0.0023, and the air quantity for the high-speed condition was reduced to about 2/3 of the original amount.

Owing to time limitations an optimum design for the Prestone radiator system could not be developed. A design of this type would include the following additional modifications:

1. A larger radiator so as to decrease the internal radiator drag to less than 1 percent of the airplane drag.

2. A rearrangement of the piping at the rear of the engine so as to allow the radiator outlet to be lengthened and so discharge the cooling air parallel to the under surface of the fuselage.

3. A flapped outlet to provide additional cooling air for the climb condition.

4. A flapped inlet, if necessary for ground cooling or extra cooling in climb.

With the ideal arrangement the cooling drag should not exceed 4 to 5 percent of the airplane drag.

Wing drag. - The results of the measurements of the wing profile drag by the momentum method are shown in figure 15.

The profile drag coefficients given are based on an average wing $C_L = 0.135$. The results were obtained at a tunnel speed of 80 miles per hour which corresponds to a Reynolds Number of about 5 million based on the average wing chord. Included in figure 15 is a curve for an estimated aerodynamically smooth wing of the same geometrical characteristics.

Compared with the estimated average smooth wing C_{D_0} of 0.0060 the coefficient for the service wing, including the completely faired landing gear and the wing fillets, was 0.0094. By means of an extrapolation (see dotted line in fig. 15) an attempt was made to separate the drag of the landing gear and fillets from that of the wing. By this method the average drag of the wing alone was estimated to be 0.0079 or 31.5 percent greater than that of the smooth wing. Also, based on the preceding assumptions, the drag of the landing gear and fillets was 0.0016 or 8 percent of the entire smooth airplane drag.

In order to further investigate possibilities for reducing the wing drag and to aid in separating that part of the added wing drag which was due to early transition from that due to surface roughness, measurements of the transition points were made for several sections of the wing at several angles of attack. The transition point is defined as the chordwise station on the wing at which the laminar flow in the boundary layer begins to change to turbulent flow, and is experimentally observed as the point at which the velocity next to the surface begins to increase rapidly. The locations of the transition point for two stations measured are shown in figure 16. Transition occurred at approximately the 10 percent chord point for the inboard station and at the 17-1/2 percent chord point for the outboard station. The measurements were confined to the upper surface only since the transition point on the lower surface for the lift coefficient tested occurs almost at the front stagnation point even for a smooth wing. Measurements on a similar smooth airfoil (reference 3) showed the transition point to occur at the 24 percent chord point. The effect of the roughness on the nose of the airfoil moved the transition point forward an average of about 10 percent. Tests on a smooth wing have shown that moving the transition point forward by this amount on both surfaces increases the wing profile drag by about 10 percent.

With this information an attempt has been made to separate the total measured increase in wing drag for the XP-40 airplane into the separate components. These are as follows:

1. Tips of wings ----------------------0.0002
2. Aileron slot ----------------------0.0001
3. Irregularities at tips of flaps and ailerons --------------------0.0003

4. Movement of transition point--- 0.0003
5. Countersunk rivets ----------- 0.0002
6. Joggled laps and manufacturing irregularities-------------- 0.0008

These increments represent the drag of the various items at a tunnel velocity of 80 miles per hour. It is next necessary to predict the effect of these same items at the actual high speed of about 350 miles per hour. It is believed that items 1, 2, and 3 will remain essentially the same. Owing to the fact that the transition point even for a smooth wing at 350 miles per hour would occur at about 10 percent of the wing chord back of the stagnation point, there is little to be gained by attempting to delay transition on the present wing. From high-speed tunnel results (reference 4) it may be noted that the drag of joggled laps is about the same at Reynolds Number of either 5 or 20 million, so this increment is likely to change but little. It may be desirable, however, to eliminate the lap joints and attempt to produce a smooth wing by filling the wing surface. In this way the drag increment of 0.0008 for the laps and manufacturing irregularities may be somewhat reduced. The C_D item of 0.0002 for the countersunk wing rivets may also be largely eliminated in this way.

The drag increment of 0.0001 obtained for the aileron gap from the momentum measurements is small, but is consistent with the results of other similar tests in this tunnel. The momentum measurements showing the effect of sealing the gap between the stabilizer and elevator are shown in figure 17. The airplane C_D was decreased by 0.0002 due to the elevator seals. If the seals on the vertical surfaces contribute the same amount, the total increment due to the seals on all the surfaces would be 0.0005, which is in good agreement with the force test results.

Carburetor intake. - An attempt was made to improve the carburetor intake by a redesign of the inlet scoops. The original and modified scoop arrangements are shown in figures 10 and 18. The two scoops in the original arrangement were combined into a single central scoop with the blast tubes removed. The scoop was partly sunk below the original upper cowl line. (See fig. 18.)

The drag coefficient for the modified scoop was about 0.0002 less than for the original one; however, the pressure available at the carburetor was also decreased to about two-thirds of that available with the original scoop. Since this decrease in pressure would result in a lower carburetor ram at altitude, the advantage of the decreased drag of the modified carburetor inlet is dubious. It is believed that an optimum design of the carburetor inlet would consist of a single scoop, similar to the modified one used in the present tests, but with its opening further forward so as to avoid the loss in ram pressure due to the fuselage boundary layer. Care must be taken to provide smooth cowl lines ahead of the scoop, and the nose radius and external shape of the scoop should be designed so as to provide a smooth passage for the air flowing around it.

Holes in propeller spinner. - Completely sealing the hole in the nose of the propeller spinner and the gaps around the propeller blades decreased the airplane drag coefficient by 0.0007. This increment was obtained from the power-on tests since it was considered to be particularly sensitive to the conditions of propeller operation. It is believed that the hole at the nose of the spinner should be eliminated and the gaps around the propeller blades largely reduced. If cooling is required for the propeller motor, it is suggested that metal fins be used to conduct the heat from the motor casing to the spinner shell.

Landing gear and other items. - Refairing the entire landing gear (fig. 5) reduced the airplane drag by a C_D increment of 0.0009. A separate test showed that most of this reduction was due to improvements to the forward part of the retracted gear, as a reduction of 0.0007 was obtained for the faired condition with the rear wheel cover plates removed. (See arrows in fig. 5.) As pointed out in the discussion of the wing drag, an increment of 0.0016 is attributed to the completely faired landing gear and wing fillet. Assuming that one-half of this increment is due to the landing gear, it is to be observed that a further C_D reduction of about 0.0008 is possible making the total gain from completely retracting the landing gear within the wing or fuselage about 0.0017.

The inlets to the oil cooler ducts (fig. 3) increased the drag coefficient by 0.0003. This increment is excessive and indicates a very low duct efficiency; however, without a major redesign of the oil-cooling system little opportunity for a large improvement seems possible.

The aerial contributed the surprisingly large drag increment of 0.0005. This item could be eliminated through the use of the trailing antenna.

The exhaust stacks increased the drag coefficient by only 0.0003 and aerodynamically are excellent in design.

<u>Critical compressibility velocities</u>. - Measurements were made of the maximum negative pressures on the wing, engine cowl, and windshield for the high-speed flight attitude to aid in predicting the critical compressibility velocities. The method for determining the critical velocities from the pressure measurements is given in

reference 5. This method is outlined in figure 19, the critical velocity being given by the intersection of the curve designated as P with the critical velocity curve marked P_c. The pressure coefficient P equals p/q in which p is the local static pressure and q is the free stream dynamic pressure.

From the data of figure 19, the following critical velocities are tabulated:

CRITICAL VELOCITY, M. P. H.		
	Ground	16,000 Ft. Alt.
Cowling	667	630
Wing	500	473
Windshield	408	390

The results show that the critical velocity occurs first at the corner of the windshield at a velocity of 390 miles per hour.

The results predicted by the method of reference 5 are not conservative, and the actual compressibility burble may occur at a speed as much as 10 to 20 miles per hour lower than given in the table. It is believed that if a speed of 370 miles per hour is expected from the XP-40 airplane, it is desirable to further round over the peak of the windshield. The studies of reference 6 will aid in this work.

CONCLUDING REMARKS

Based on the test results it is estimated that modifications to the airplane that are immediately practicable such as sealing slots, utilizing trailing antenna, closing spinner holes, fairing landing gear, and modifying the radiator installation would increase the top speed by about 23 miles per hour. Incorporating the further refinements of completely retracting the landing gear, increasing the size of the radiator and providing an optimum radiator duct, smoothing the wing, redesigning the carburetor inlet, redesigning the oil-cooler system so as to obtain a higher duct efficiency, and improving the wing fillets could result in a total increase in maximum speed of about 42 miles per hour.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 16, 1939.

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V

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2. Goett, Harry J.: Experimental Investigation of the Momentum Method for Measuring Profile Drag. Technical Report No. 660, N. A. C. A., 1939.

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4. Hood, Manley J.: The Effects of Some Common Surface Irregularities on Wing Drag. Technical Note No. 695, N. A. C. A., 1939.

5. Stack, John, Lindsey, W. F., and Littell, Robert E.: The Compressibility Burble and the Effect of Compressibility on Pressures and Forces Acting on an Airfoil. Technical Report No. 646, N. A. C. A., 1938.

6. Robinson, Russell G., and Delano, James B.: The Drag of Closed-Cockpit and Transport-Type Windshields at High Speeds. Confidential Memorandum Report, N. A. C. A., March 1, 1939.

FIGURE LEGENDS

Figure 1. - The XP-40 airplane in the completely faired condition mounted in the full-scale tunnel.

Figure 2. - Lower fuselage fairing.

Figure 3. - Oil-cooler duct cover.

Figure 4. - Control surface gaps sealed and open.

Figure 5. - Retracted landing gear.

Figure 6. - Modified radiator installation.

Figure 7. - Modified and original radiator installations. (Sketch)

Figure 8. - The XP-40 airplane in original condition minus aerial.

Figure 9. - Original radiator installation.

Figure 10. - Carburetor inlet scoops.

Figure 11. - Drag of airplane at high-speed attitude for various test conditions.

Figure 12. - Scale effect on high-speed drag coefficient for airplane in standard condition and in the completely faired condition.

Figure 13. - Drag reductions in percent from various modifications to the airplane.

Figure 14. - Lift, drag, and pitching moment for airplane in the standard condition, propeller off.

Figure 15. - Wing profile drag obtained from momentum measurements in the wake of the wing.

Figure 16. - Determination of transition point on upper wing surface.

Figure 17. - Profile drag of horizontal tail surface, gaps sealed and open, as obtained from momentum measurements in wake.

Figure 18. - Original and modified carburetor intake scoops. (Sketch)

Figure 19. - Critical velocities for windshield, wing, and nose of airplane.

TABLE I

	Test Condition	High speed C_D	Increment of drag reduction ΔC_D
1	Smooth fuselage condition; propeller off; radiator retracted and completely faired over; exhaust stacks removed; windshield closed; landing gear faired over; slots in control surfaces sealed; all spinner openings sealed; bottom of fuselage faired smooth; oil duct inlets covered; carburetor inlet scoops and blast tubes off; aerial and fittings off; control surfaces locked neutral; airplane clean of dust and dirt.	0.0196	
	Lower fuselage fairing produced negligible drag increment so has been omitted from the summary of test conditions.		
2	Same as 1 except oil cooling ducts opened.	0.0199	0.0003
3	Same as 2 except exhaust stacks added.	0.0203	0.0004
4	Same as 3 except seals on control surfaces off.	0.0209	0.0006
5	Same as 4 except rear cover plates off landing gear.	0.0211	0.0002
6	Same as 5 except forward landing gear fairings off.	0.0218	0.0007
7	Same as 6 except carburetor inlets added and faired.	0.0221	0.0003
8	Same as 7 except blast tubes added, fairings remaining on carburetor inlets.	0.0221	0.0000
9	Same as 8 except modified radiator scoop on.	0.0241	0.0020
10	Same as 9 except original radiator scoop with restricted outlet on.	0.0244	0.0003
11	Same as 10 except original radiator scoop and modified carburetor scoop on. No blast tubes.	0.0256	0.0012
12	Same as 11 but with original radiator scoop and original carburetor scoops on.	0.0258	0.0002
13	Same as 12 but with aerial and fittings added This was the original condition of the ship as received.	0.0263	0.0005

TABLE II

AIR FLOW QUANTITIES - CU. FT./MIN. AT TUNNEL

VELOCITY OF 75 M. P. H.

Attitude of Ship	Original Condition		Original Condition Restricted Outlet	Modified Scoop Radiator Raised	
	Power off	Power on	Power off	Power off	Power on
High Speed $\alpha = 0.6^{\circ}$	3100	3010	2100	3230	3200
Climb $\alpha = 5.7^{\circ}$	2900	3410		2850	3340

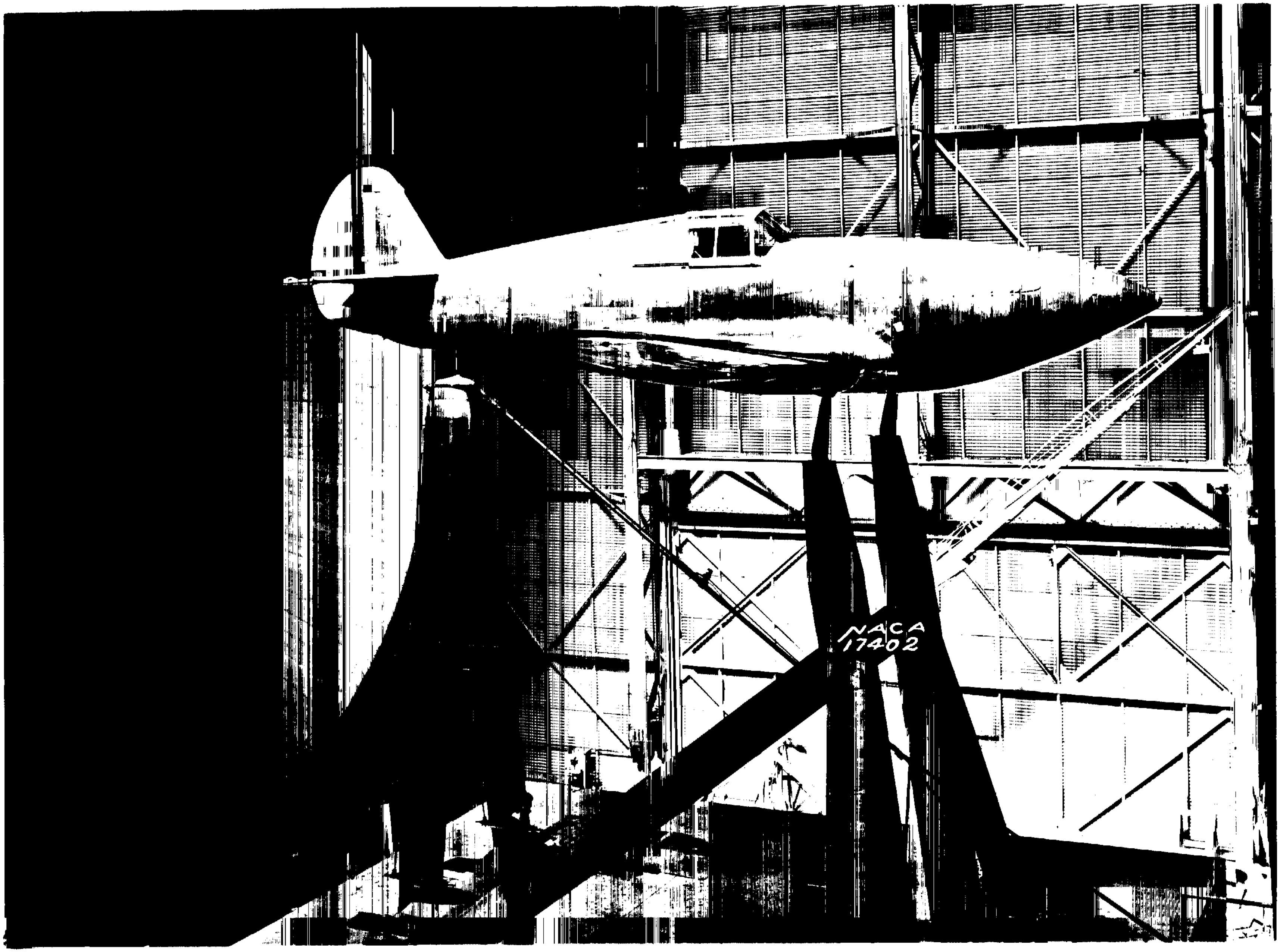

Figure 1. – The XP-40 airplane in the completely faired condition mounted in the full-scale wind tunnel.

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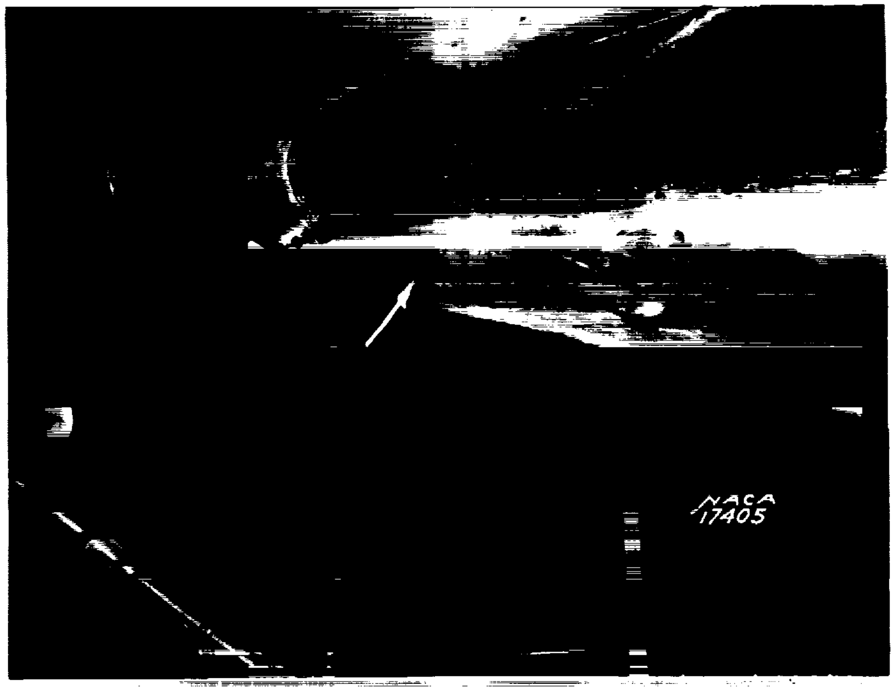


Figure 2. – Lower fuselage fairing.

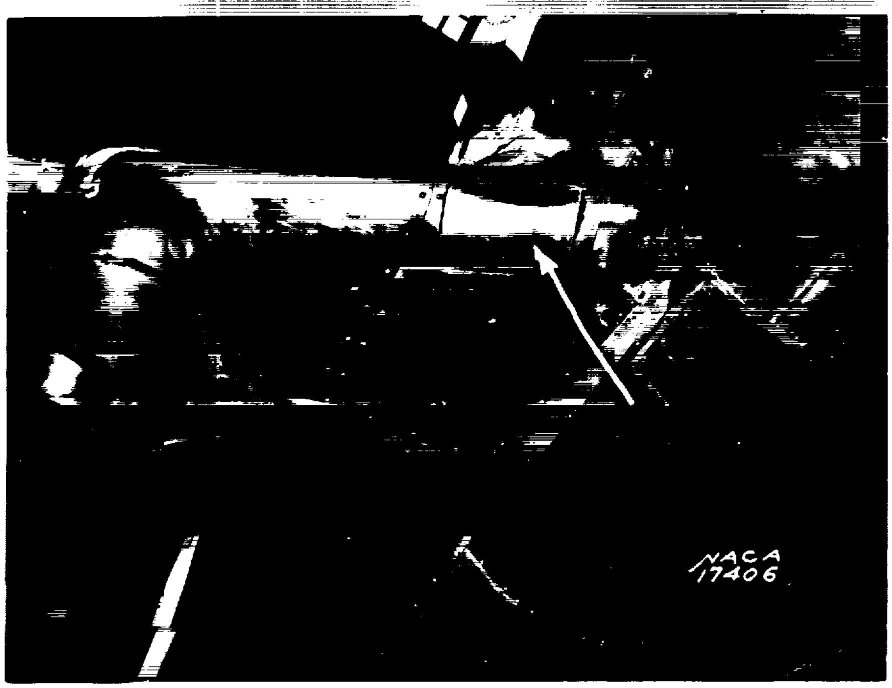
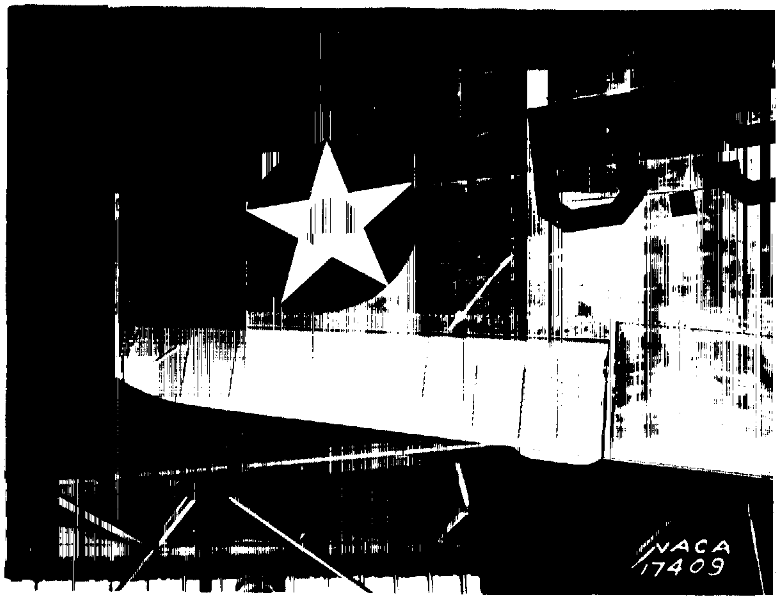
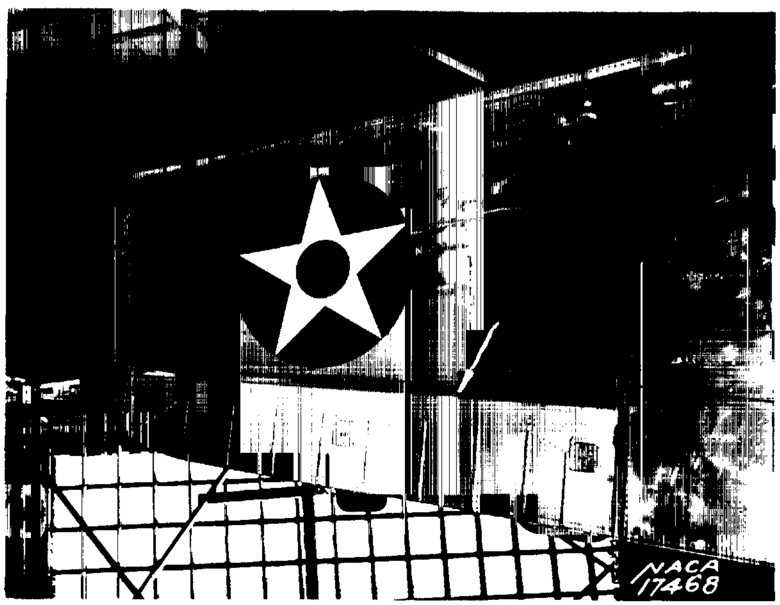


Figure 3. – Oil cooler ducts covered.

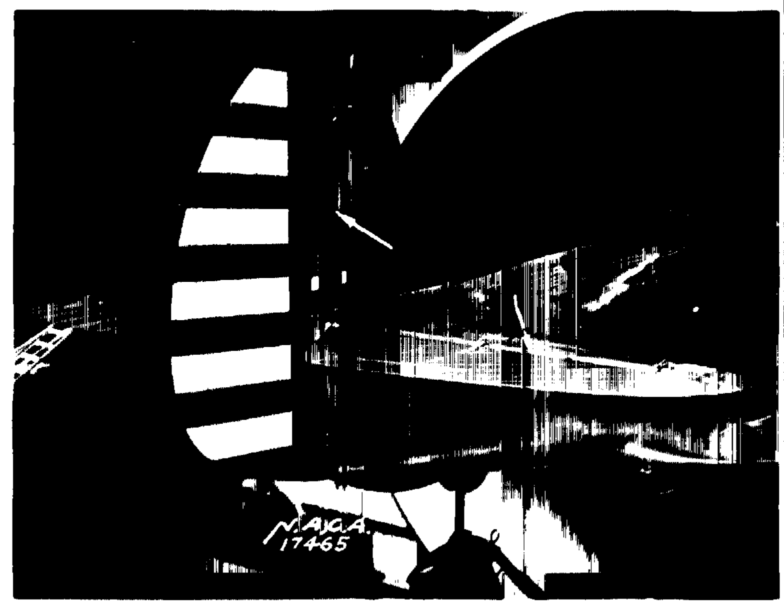


Aileron gap sealed.

Rudder and elevator gaps sealed.



Aileron gap open.



Rudder and elevator gaps open,

Figure 4.- Control surface gaps sealed and open.

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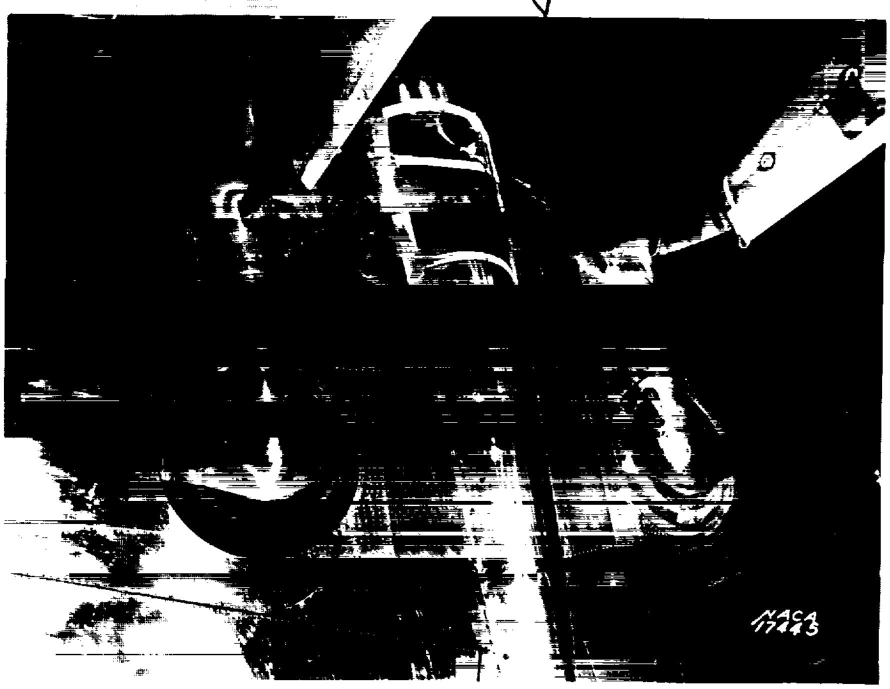
[redacted]

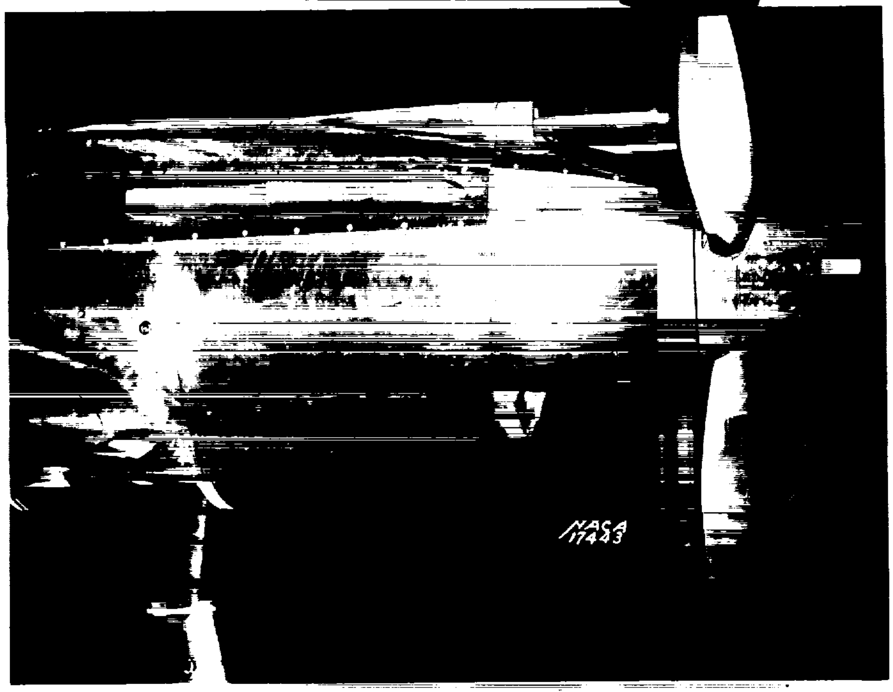
Landing gear completely faired
(A) Rear cover plate.
(B) Forward fairing.



Standard condition of landing gear.

Figure 5.- Retracted landing gear.

[redacted]



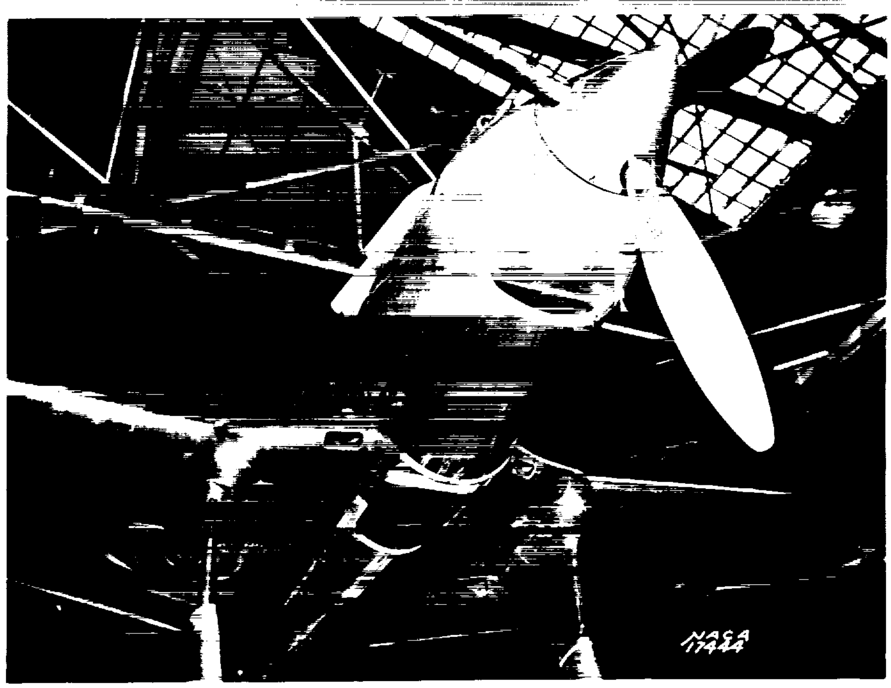


Figure 6. – Modified radiator installation.

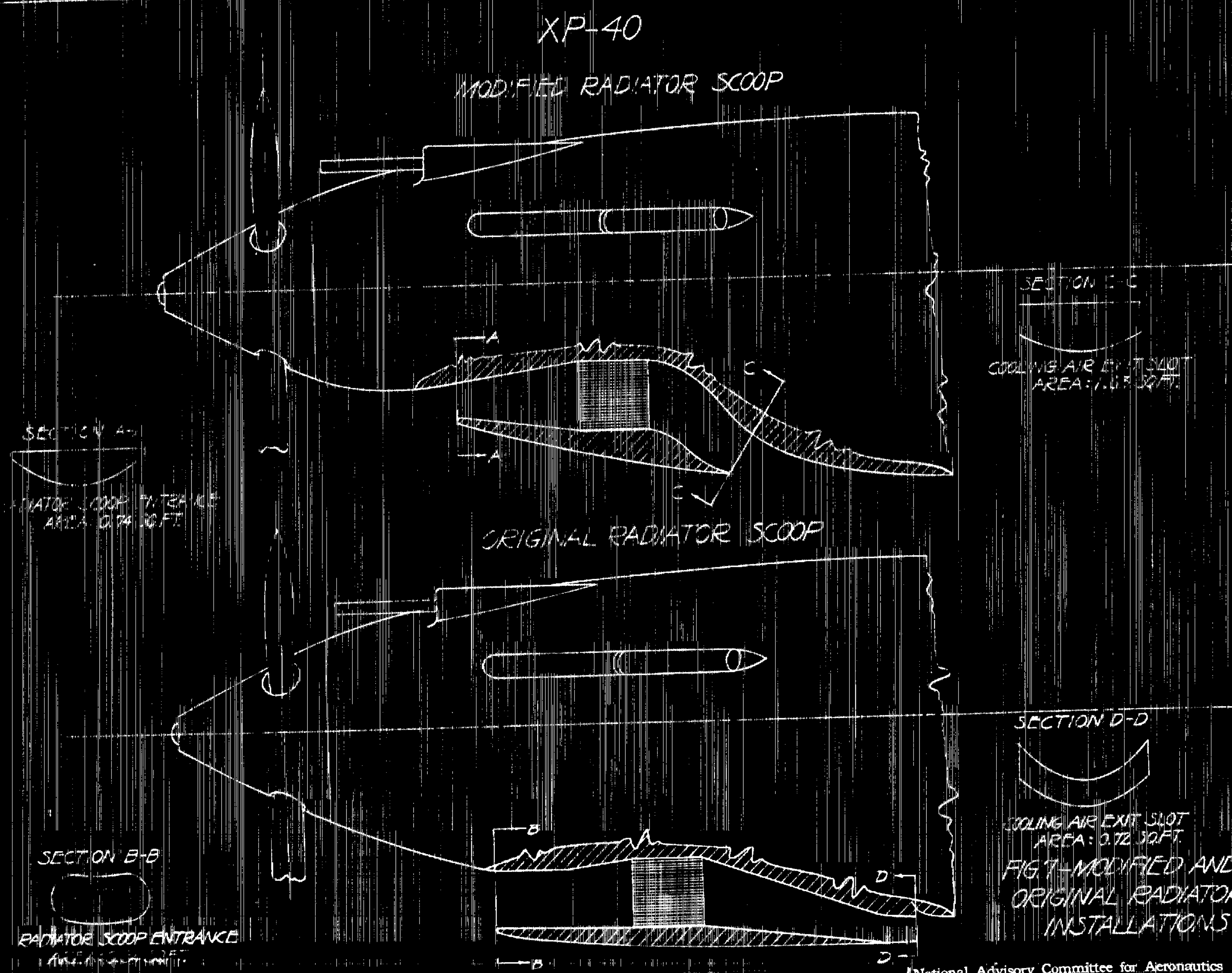


FIG. 7 - MODIFIED AND ORIGINAL RADIATOR INSTALLATIONS

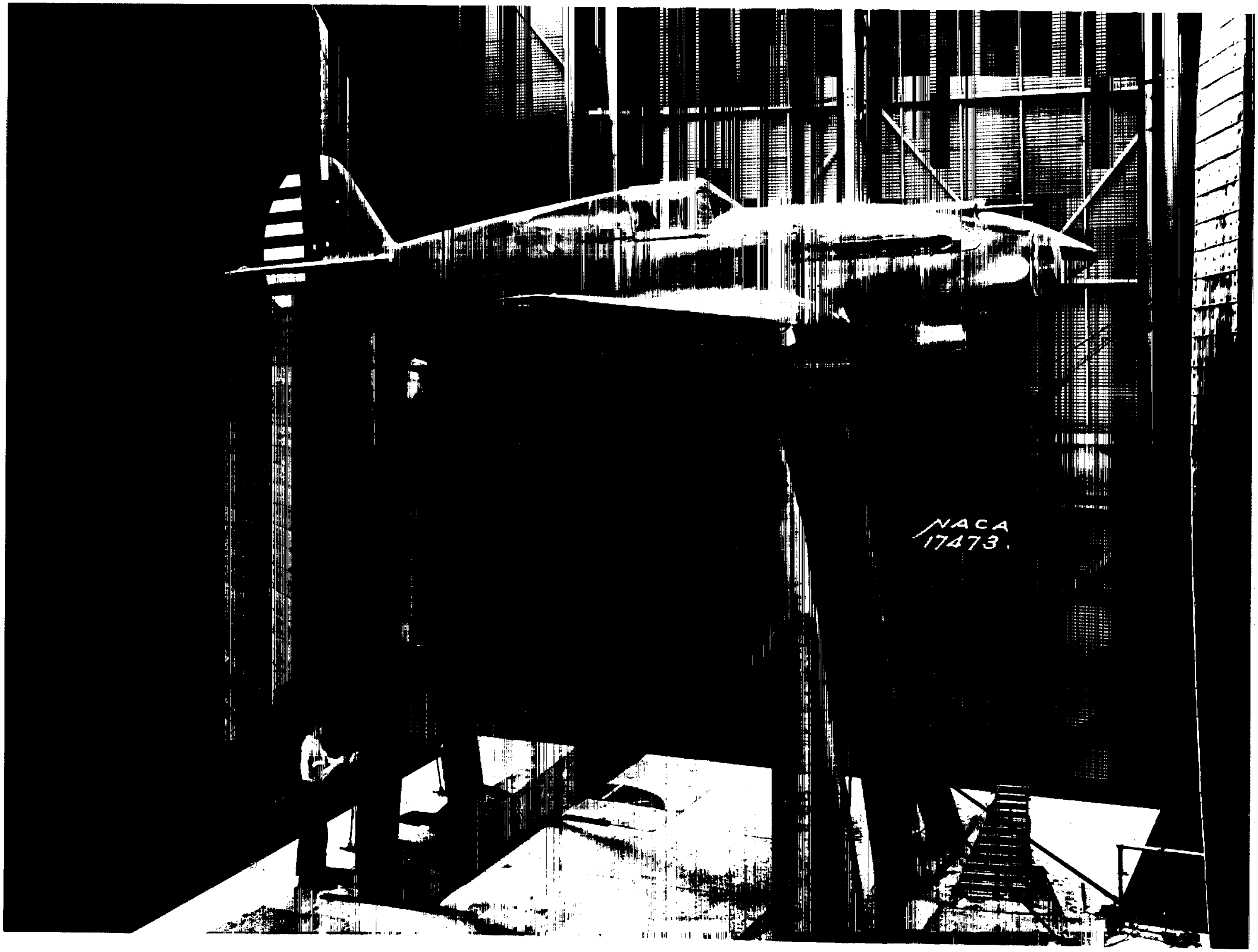
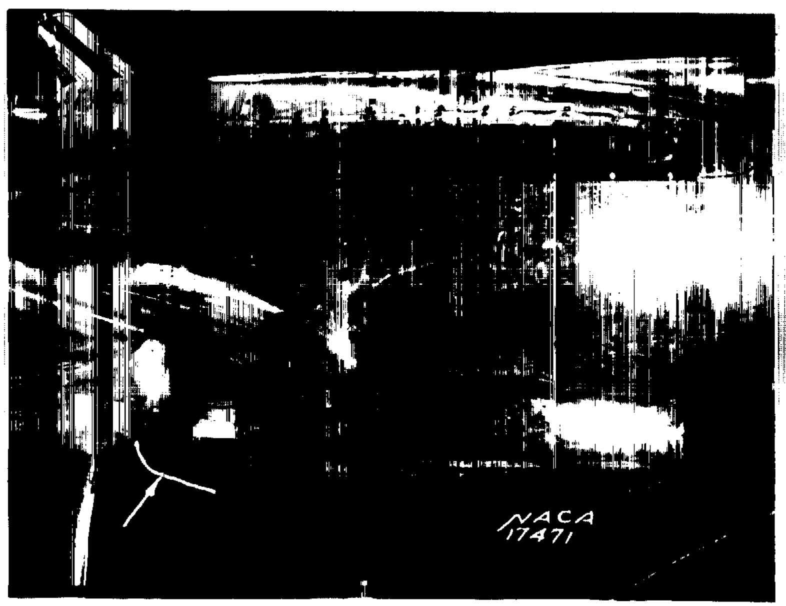


Figure 8. - The XP-40 Airplane in original condition minus aerial.

Standard condition

Faired inlet



Restricted outlet

Figure 9.- Original radiator installation.

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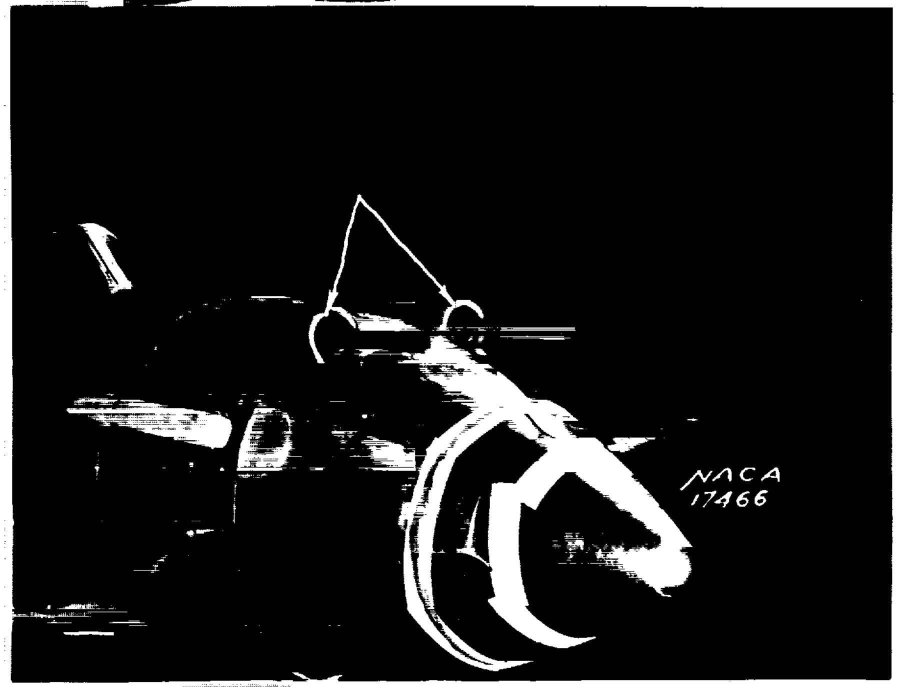
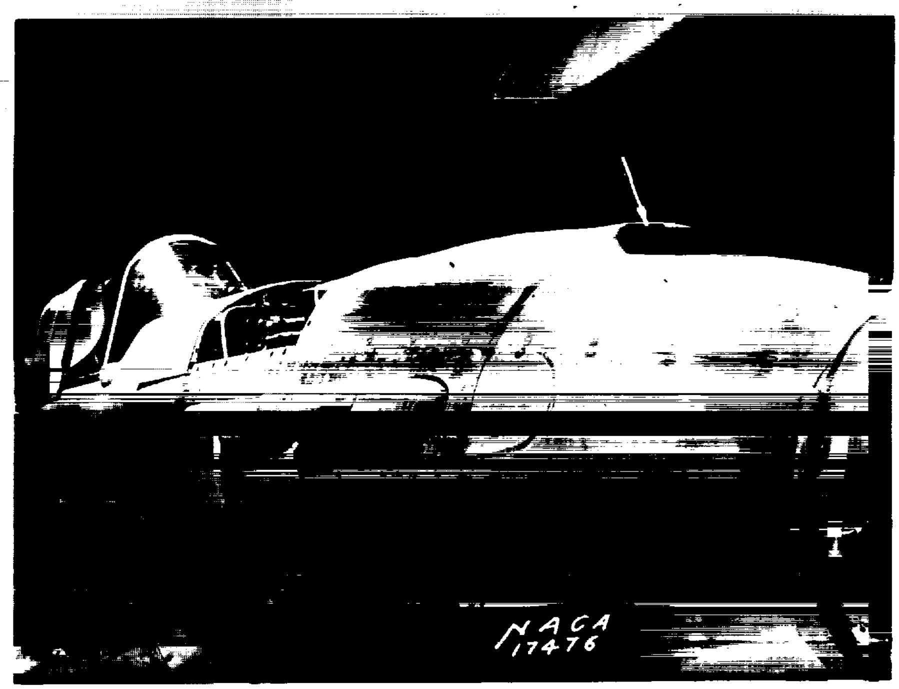


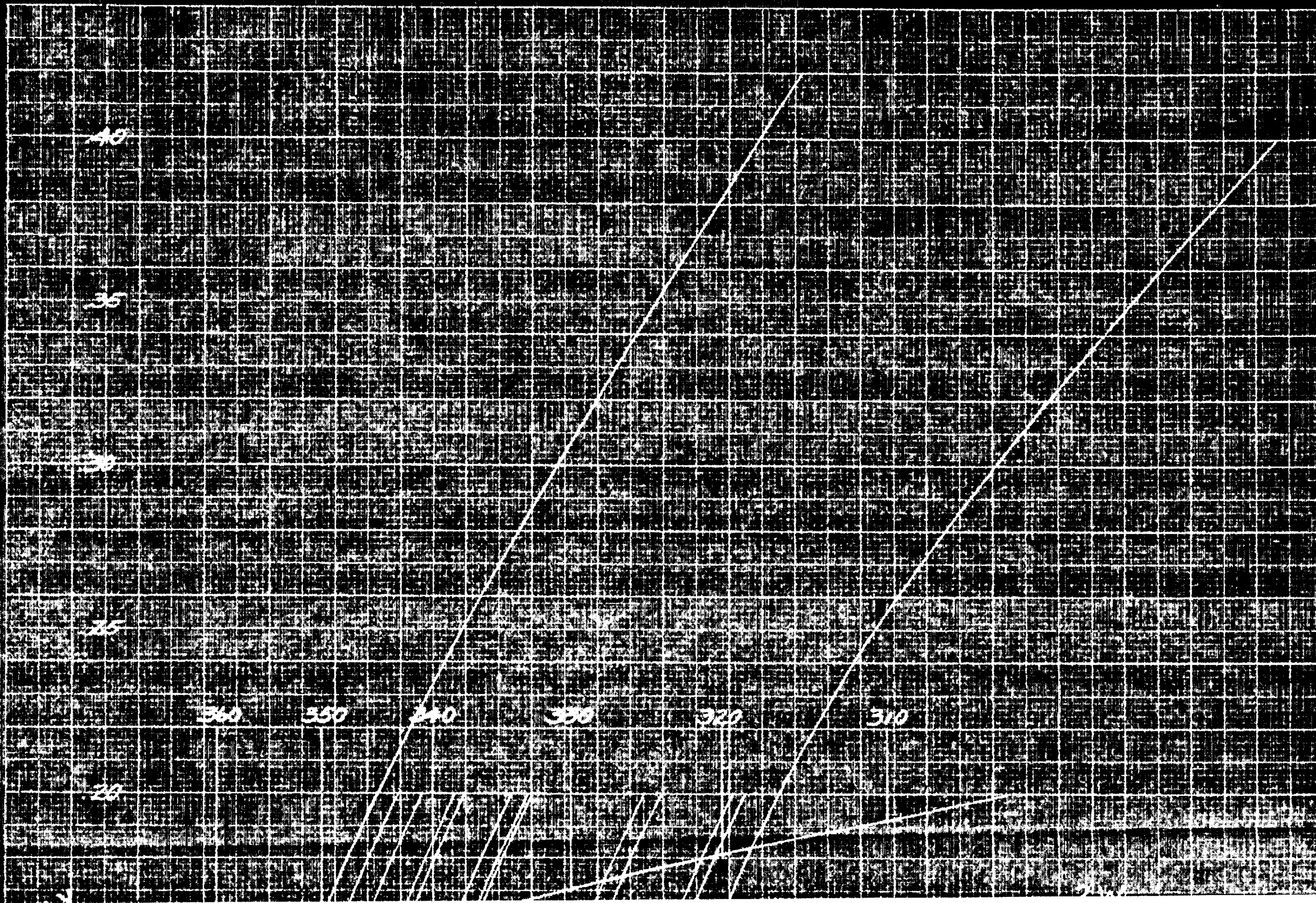
Original intake scoops.

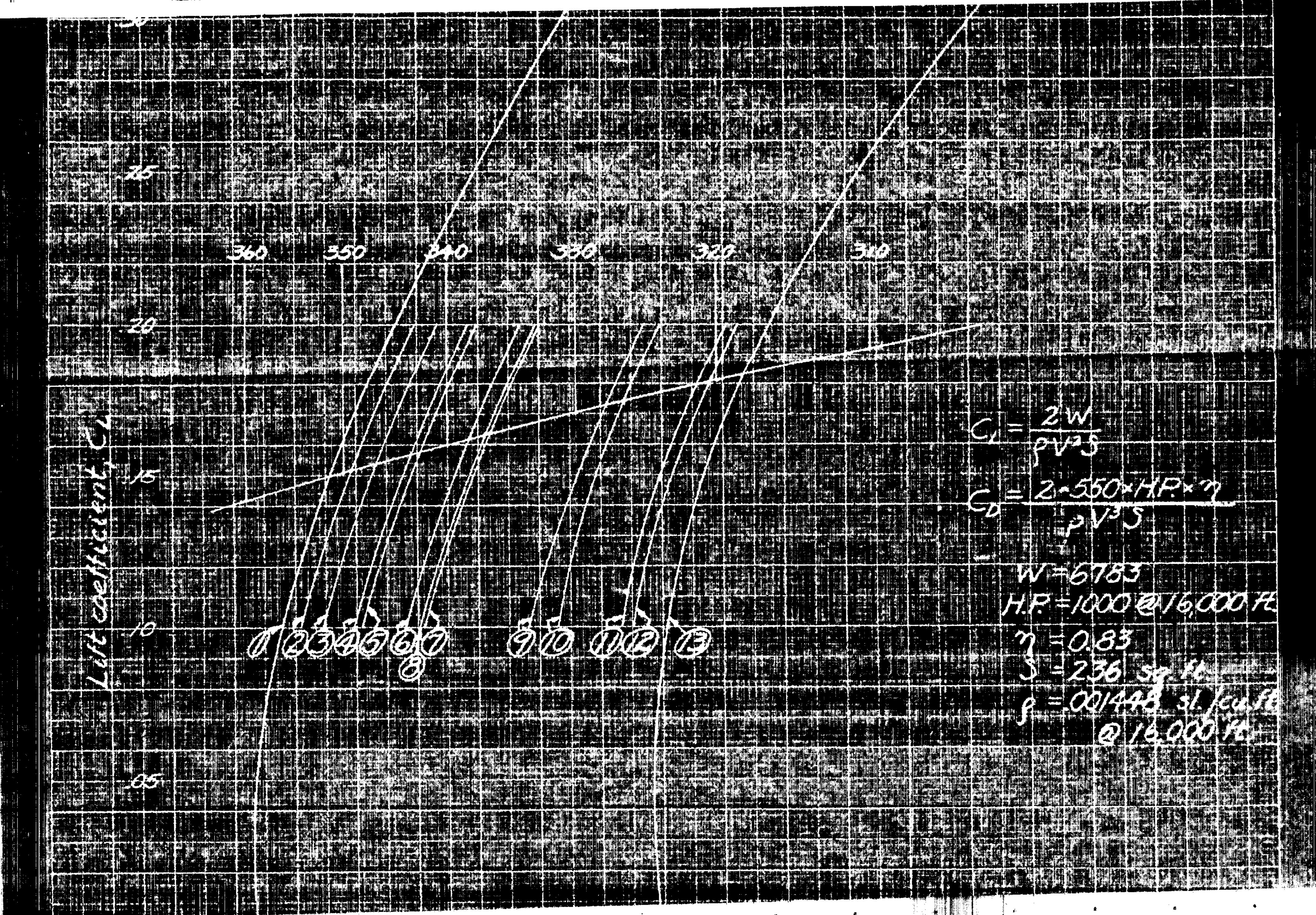


Modified intake scoop.

Figure 10. - Carburetor inlet scoops.

ENGRAVING 354-3, 10 X 10 TO THE HALF INCH.





Lift coefficient, C_L
.30
.25
.20
.15
.10
.05
360
350
340
330
320
310
1 2 3 4 5 6 7 8 9 10 11 12 13
$C_L = \frac{2W}{\rho V^2 S}$
$C_D = \frac{2 \times 550 \times H.P. \times \eta}{\rho V^3 S}$
W = 6783
H.P. = 1000 @ 16,000 Ft.
η = 0.83
S = 236 sq. ft.
ρ = .001448 sl./cu. ft. @ 16,000 Ft.

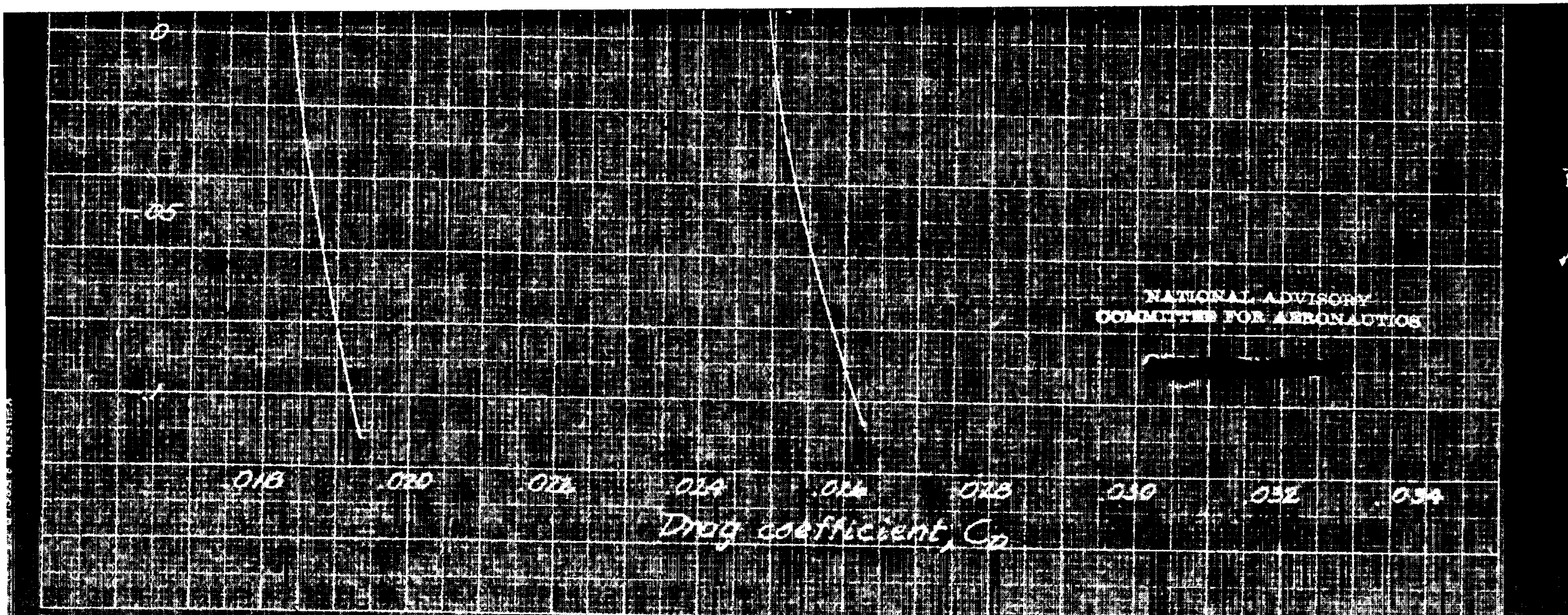
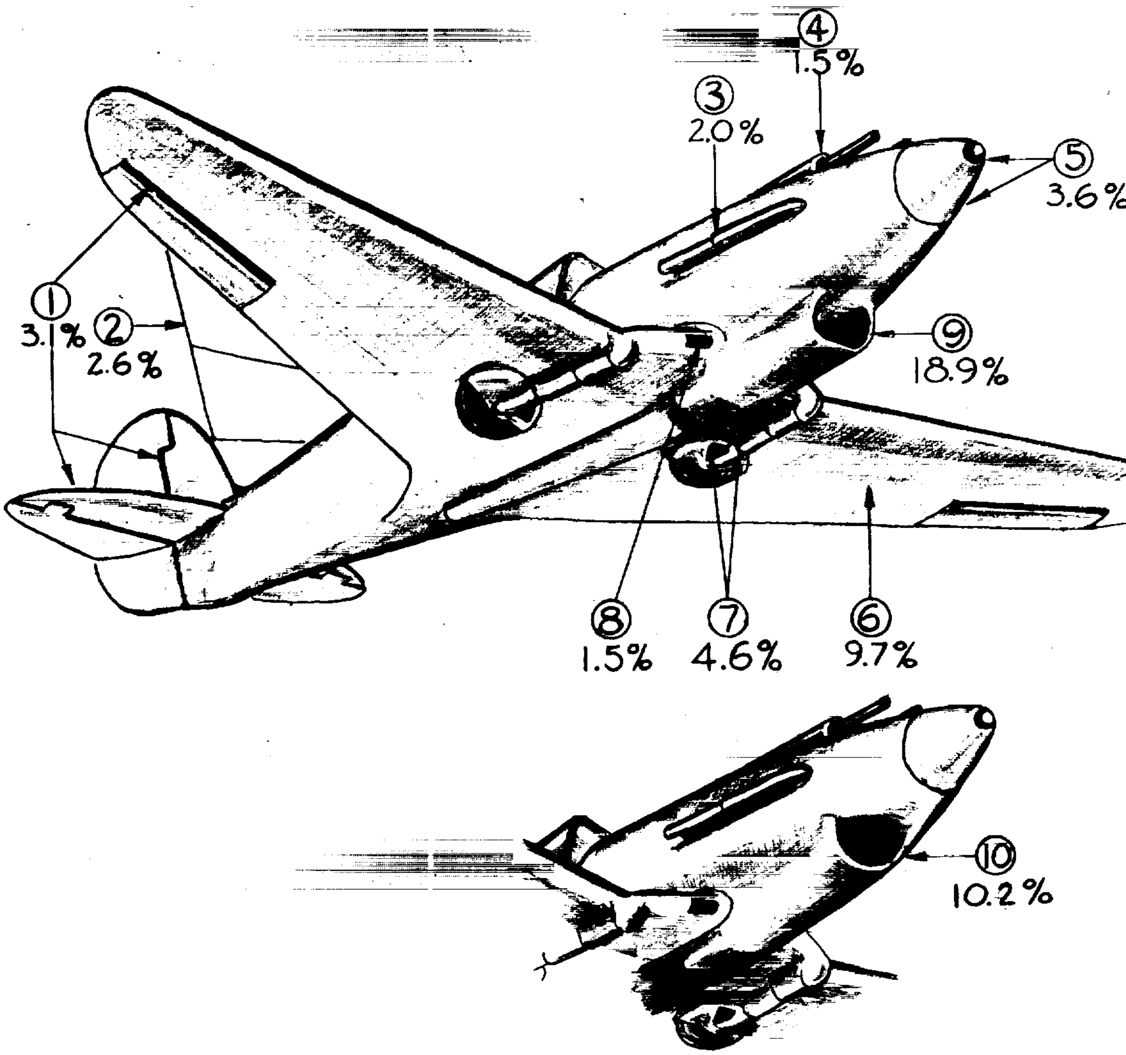


Fig. 11 Drag of airplane at high-speed attitude for various test conditions. (Note that numbers correspond with test numbers of Table I) Based on results obtained at an airspeed of 90 miles per hour.

Fig. 12 Scale effect on high-speed drag coefficient for airplane in standard condition and in the completely faired condition.



1. SLOTS IN CONTROL SURFACES
2. AERIAL
3. EXHAUST STACKS
4. CARBURETOR SCOOPS AND BLAST TUBES
5. HOLES IN SPINNER
6. WING ROUGHNESS
7. LANDING GEAR ROUGHNESS
8. OIL COOLER INLETS
9. ORIGINAL RADIATOR INSTALLATION
10. MODIFIED RADIATOR INSTALLATION

NOTE: DRAG INCREMENTS ARE BASED ON THE COMPLETELY FAIRED CONDITION (C_D=.0196)

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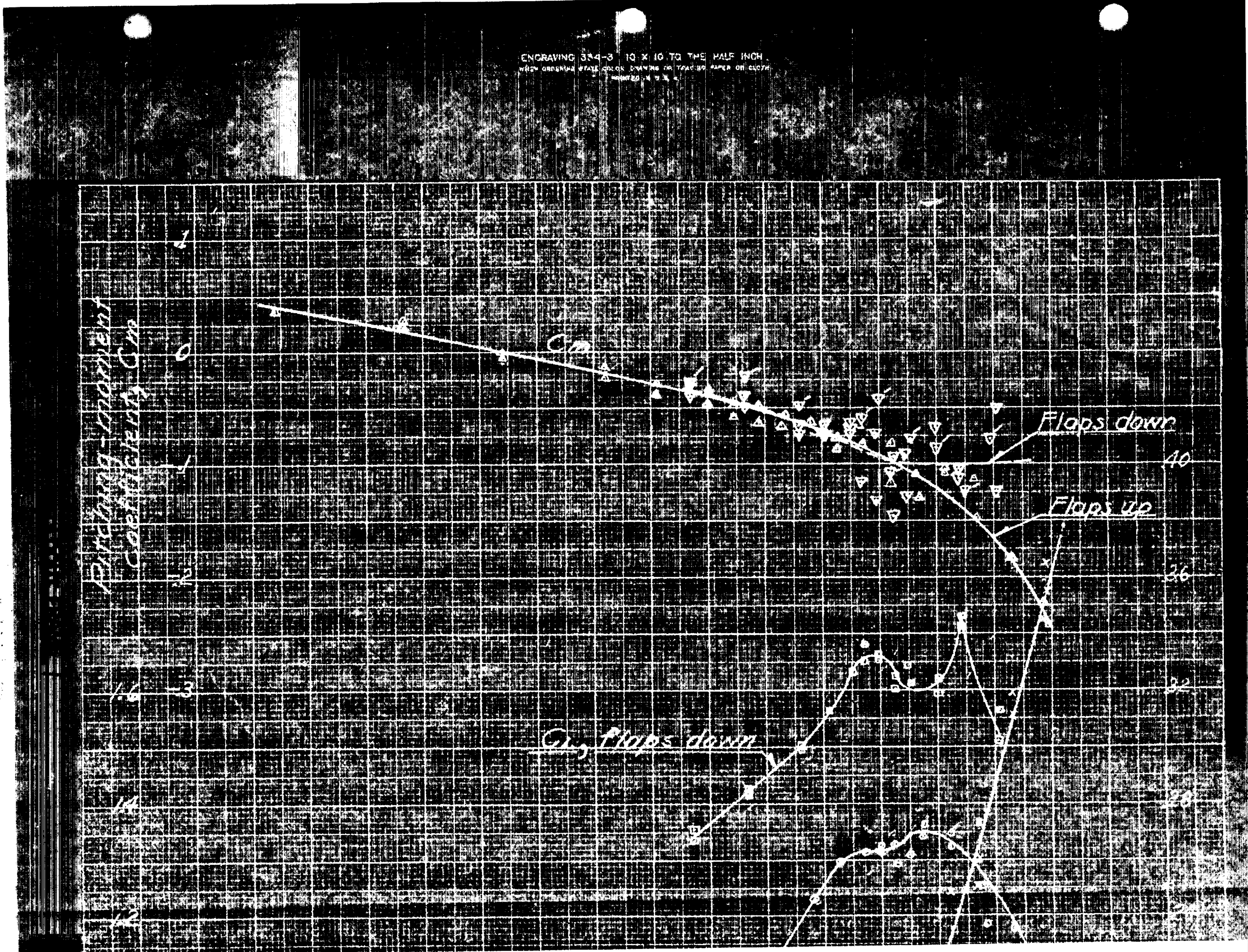
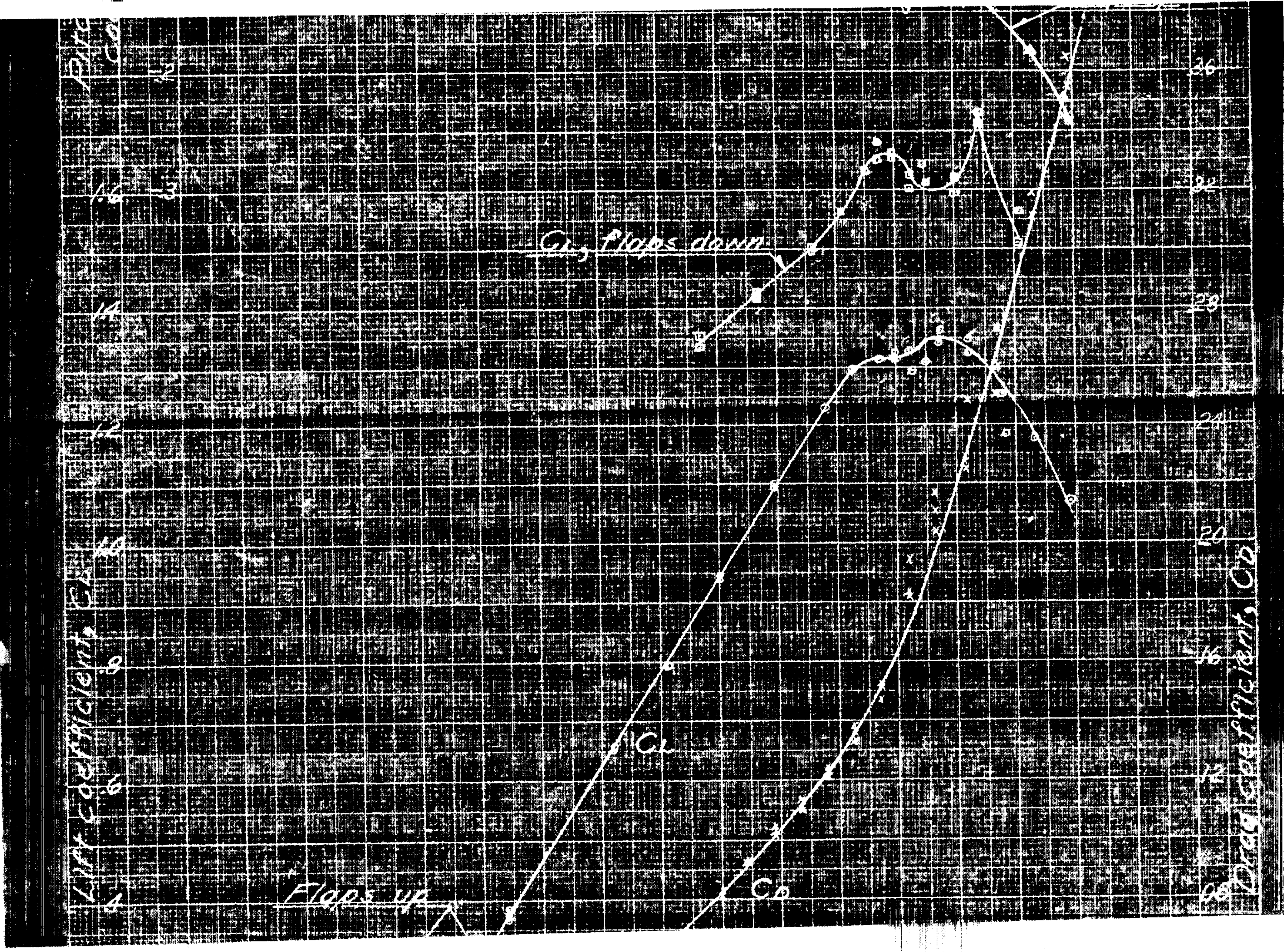
Figure 13. - Drag reductions in percent from various modifications to the airplane



ENGRAVING 334-3 10 X 10 TO THE HALF INCH
Pitching-moment coefficient, Cm
Cm
Flaps down
Flaps up
CL, flaps down
1
0
-.1
-.2
-.3
1.6
1.4
1.2
40
36
32
28


Lift coefficient, C_L
Drag coefficient, C_D
C_L, flaps down
Flaps up
C_L
C_D
1.6
1.4
1.2
1.0
.8
.6
.4
.36
.32
.28
.24
.20
.16
.12
.08

FOLDOUT FRAME 3

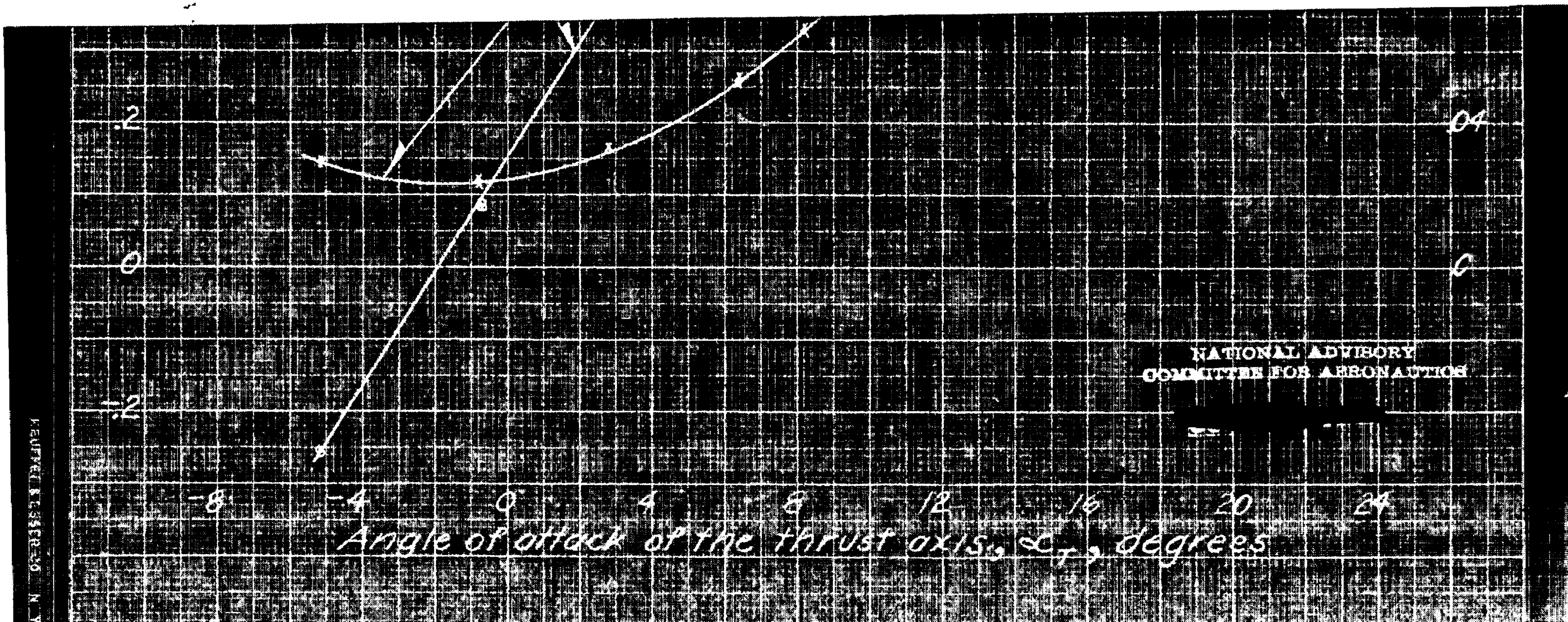


Fig. 14 Lift, drag, and pitching moment for airplane in the standard condition, propeller off. Airspeed 50 miles per hour.

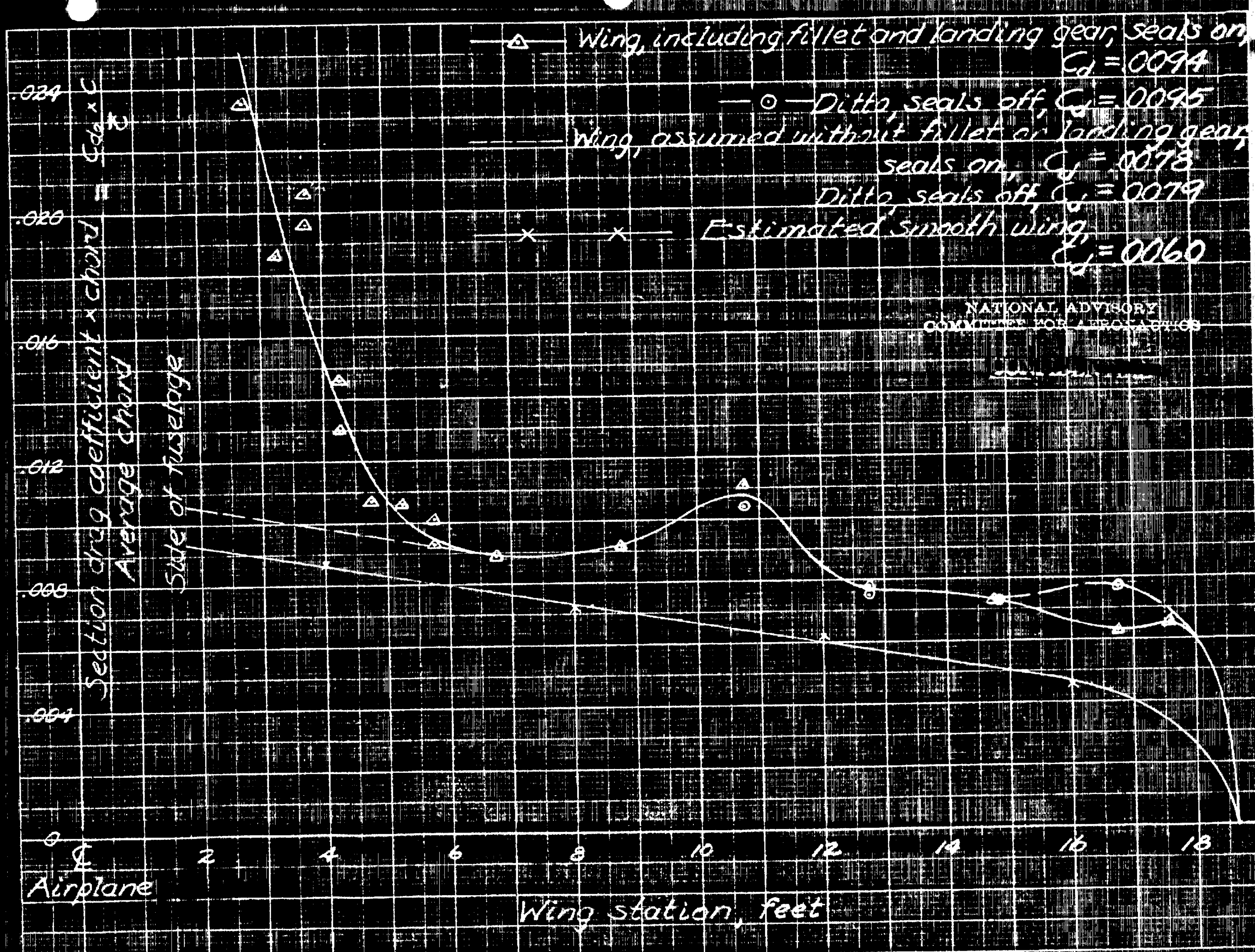


Fig. 15 Wing-profile drag obtained from momentum measurements in the wake of the wing. Airspeed, 80 miles per hour.

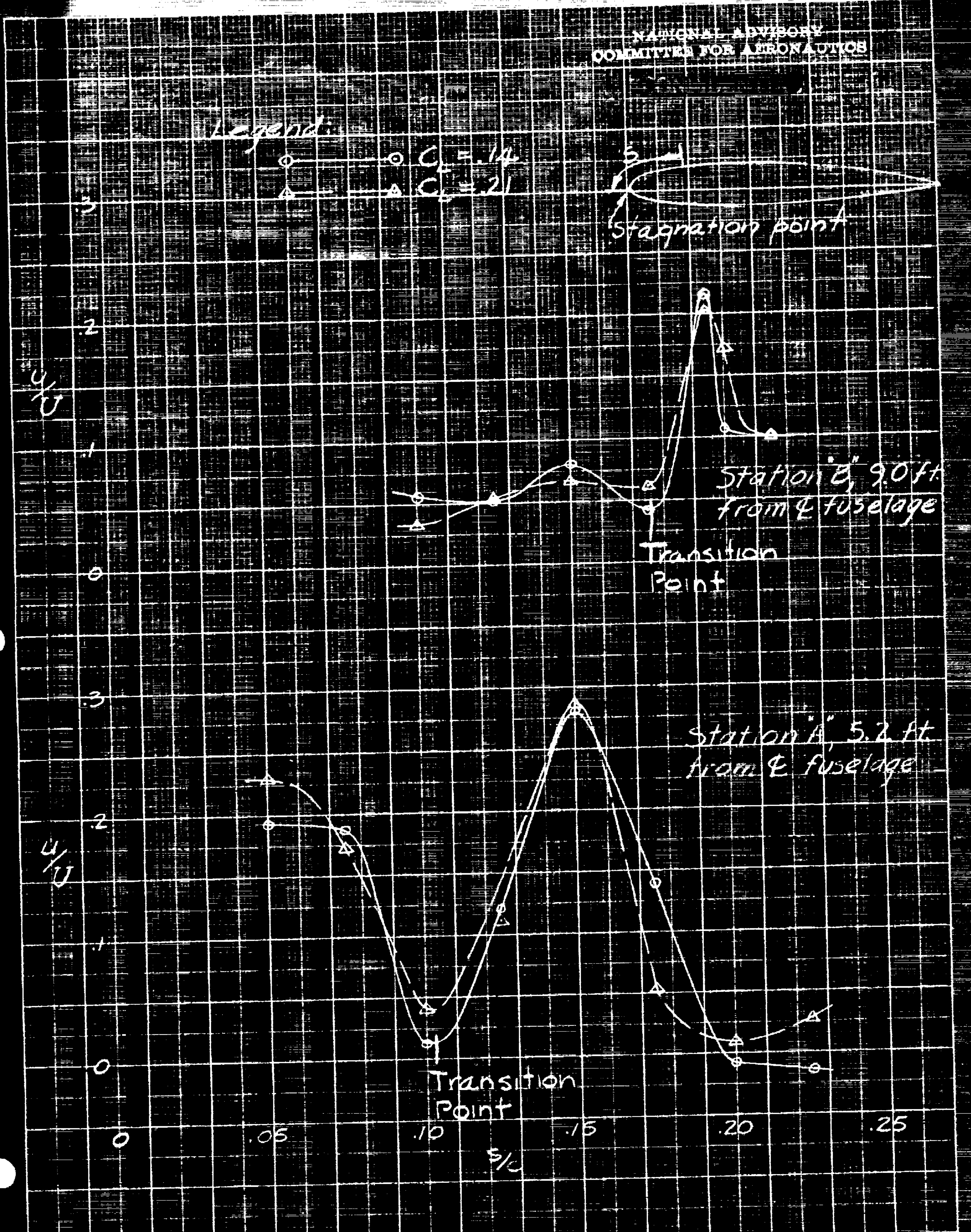


Fig. 16 Determination of transition point on upper wing surface. Airspeed 80 miles per hour.

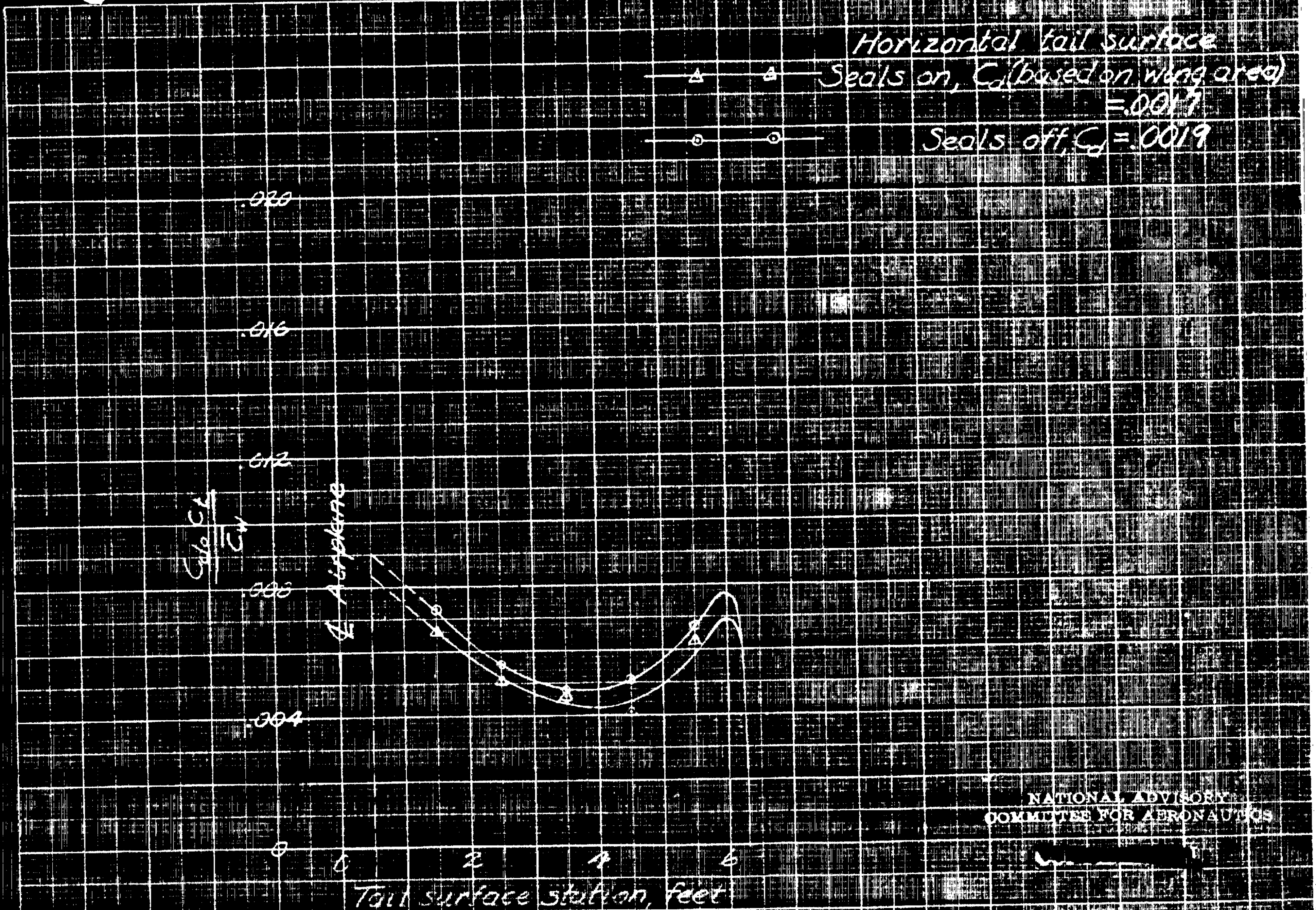


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Fig. 17 Profile drag of horizontal tail surface, seals on and off, as obtained from momentum measurements in wake. Airspeed 80 miles per hour.

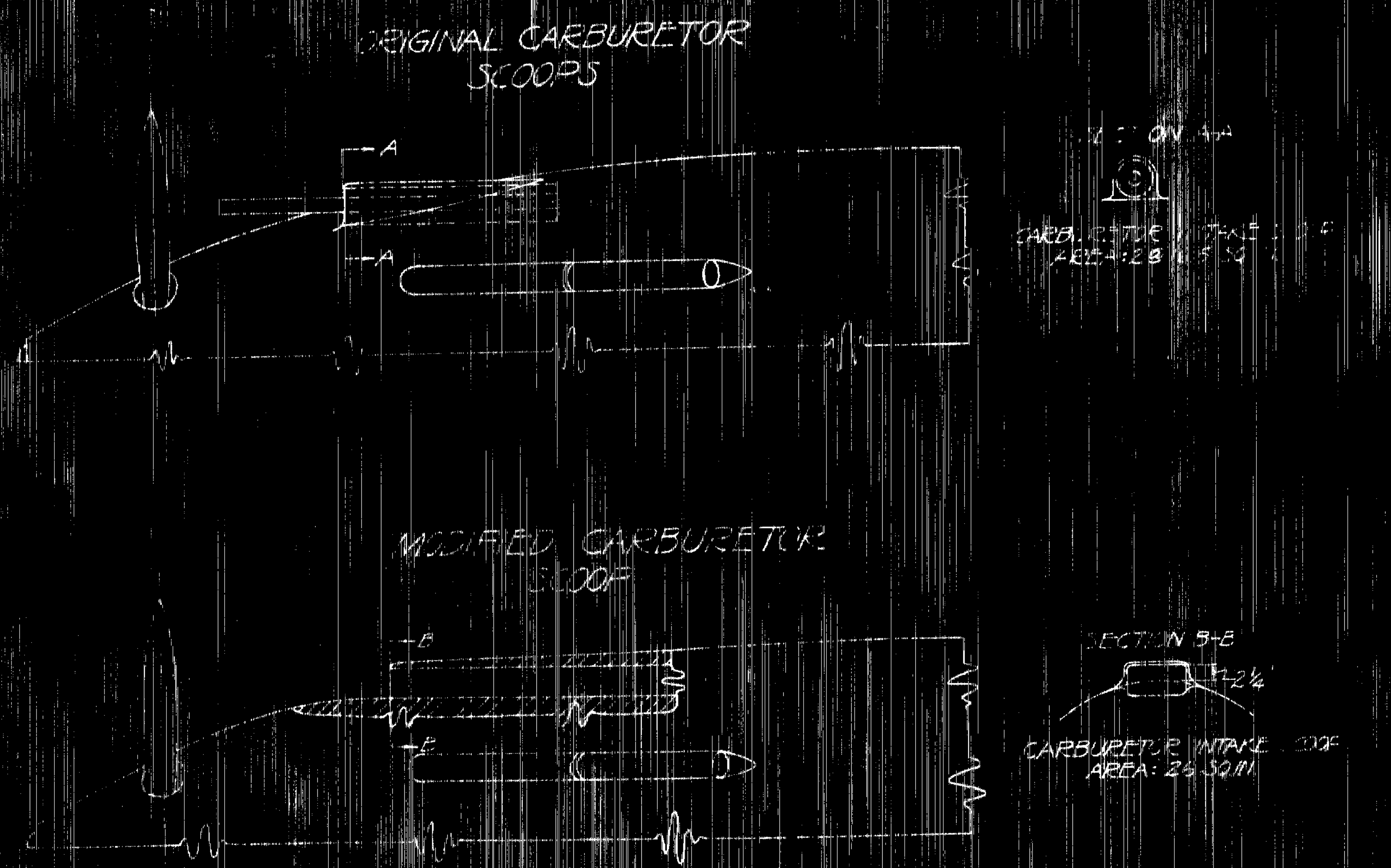
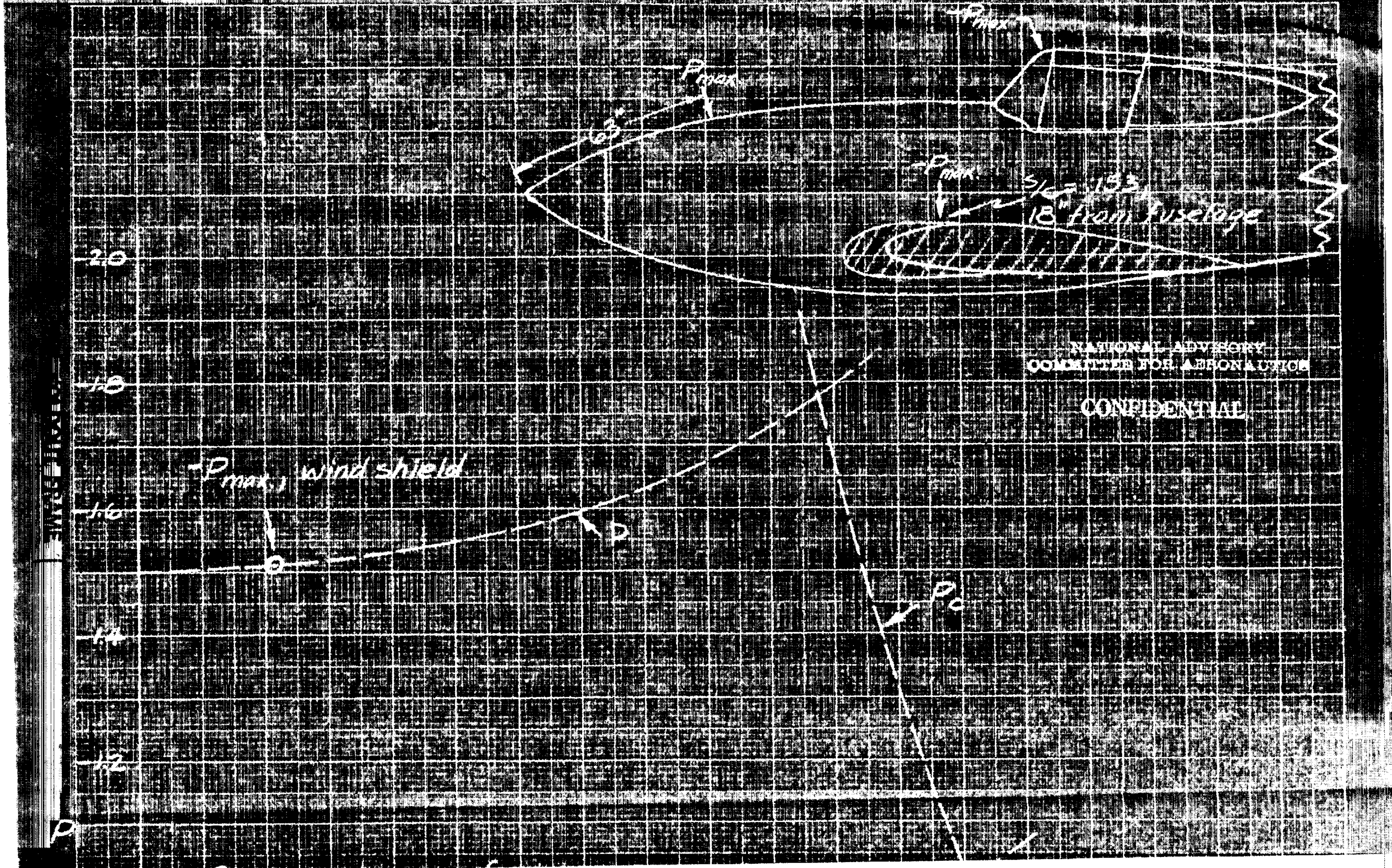


FIG. 18 - ORIGINAL AND
MODIFIED CARBURETOR
INTAKE SCOOPS



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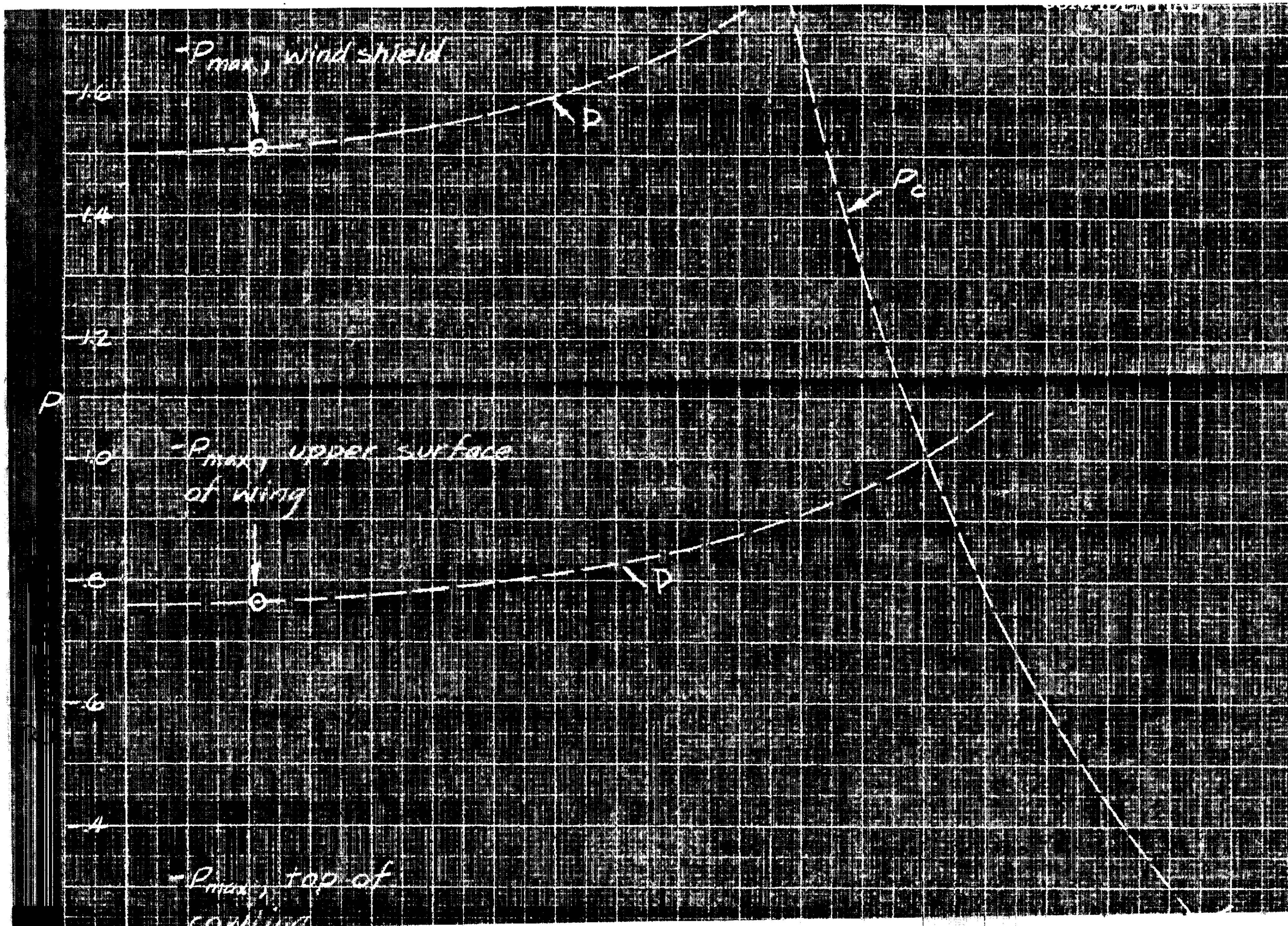

$-P_{max}$, wind shield
1.6
P
P_c
1.4
1.2
P
1.0
$-P_{max}$, upper surface of wing
P
.8
.6
.4
$-P_{max}$, top of canopy

FOLDOUT FRAME 3

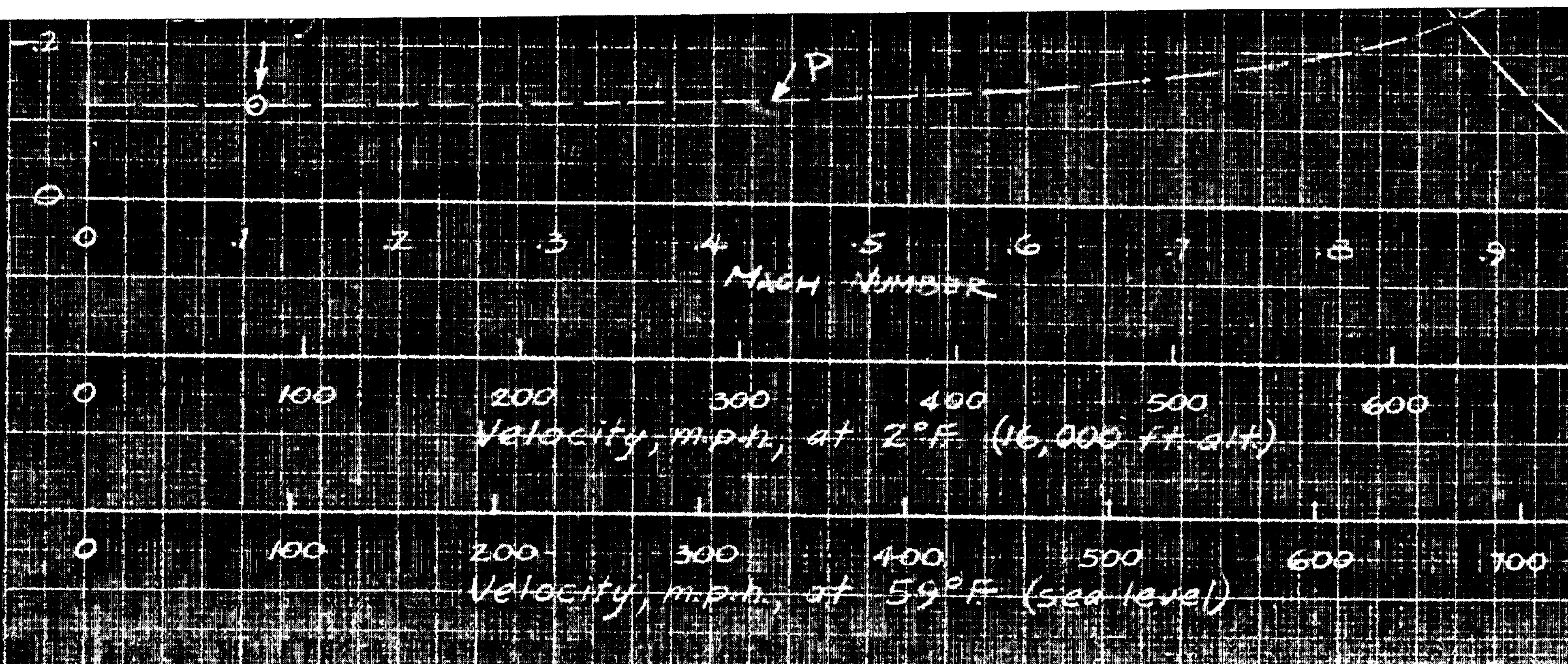

Fig. 19 Critical velocities for windshield, wing, and nose of airplane.